Technical Support Document for the Glass Manufacturing Sector: Proposed Rule for Mandatory Reporting of Greenhouse Gases

Office of Air and Radiation

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1. Industry Description

Glass is a common commercial item, divided into four common types: containers, flat (or window) glass, fiberglass, and specialty glass. Most commercial glass is used for container and flat glass and is almost entirely soda-lime glass, which consists of silica (SiO_2), soda (Na_2O), and lime (CaO), with small amounts of alumina (Al_2O_3) and other minor ingredients (IPCC 2006). Insulation grade fiberglass, a large component of the overall fiberglass market, is similar in chemical composition. Artisanal manufacturers may have slightly different propriety glass compositions that are minor variations on the above materials.

Emissions of GHGs from glass manufacturing are the result of fuel combustion and the volatilization of raw materials. Glass melting furnaces require significant amounts of energy to heat and melt the raw materials to form molten glass. This energy is usually generated through the combustion of natural gas, although other fuels may be used as a back-up to natural gas. Glass manufacturing facilities may also operate other stationary combustion sources, all of which emit GHGs.

The raw materials used in glass manufacturing include carbonates, such as limestone ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), and soda ash (Na_2CO_3). When heated in glass melting furnaces, these materials form CO_2, which is subsequently emitted from the furnace.

2. Total Emissions

National emissions from glass manufacturing were estimated to be 4,425,269 mt of CO_2 equivalent in 2004 (EPA 2006). These emissions include both process-related emissions (CO_2) and on-site stationary combustion emissions (CO_2, CH_4, and N_2O) from 374 glass manufacturing facilities across the United States and Puerto Rico. Process-related emissions account for 1,649,508 mt of CO_2[1], or 37 percent of the total, while on-site stationary combustion emissions account for the remaining 2,775,761 mt of CO_2 equivalent emissions (EPA 2006).

2.1 Process Emissions

Major carbonates used in the production of glass are limestone, dolomite, and soda ash. The use of these carbonates in the glass manufacturing process is a complex high-temperature reaction that is not directly comparable to the calcination process used in lime manufacture and limestone/dolomite use, but has the same net effect in terms of GHG emissions (IPCC 2006). Glass manufacturers may also use recycled scrap glass (cullet) in the production of glass.

[1] The *U.S. Inventory* (EPA 2008b) reports 0.7 Tg CO_2 Eq. of process emissions from glass manufacturing in 2006.

2.2 Stationary Combustion

Stationary combustion emissions occur when fossil fuels are combusted to provide energy for manufacturing equipment, as well as to provide heat for the manufacturing process. In the glass manufacturing industry, this heat is used to fuse the carbonates and other raw materials into the specified glass type. Some glass melting furnaces are heated using electricity. For non-electric glass melting furnaces, coal, natural gas, distillate fuel oil, and residual fuel oil are all possible fuel inputs, although most, if not all, are fired with natural gas. The actual mix of fuels will be site-specific.

Refer to EPA-HQ-OAR-2008-0508-004 for reporting options for emissions (CO_2, CH_4, and N_2O) from stationary combustion. However, some monitoring options discussed in Section 6 will capture total emissions at glass manufacturing sources and will sufficiently meet or be consistent with reporting options discussed in the in general stationary combustion technical support document.

3. Review of Existing Programs and Methodologies

Protocols and guidance reviewed for this analysis include the *2006 IPCC Guidelines, U.S. Inventory,* the Australian National Mandatory Greenhouse Gas Reporting Program, the European Union Emissions Trading System (both the first and second reporting periods), the U.S. Department of Energy's (DOEs) Technical Guidelines for the Voluntary Reporting of Greenhouse Gases (1605(b)) Program, and the European Bank for Reconstruction and Development. Table 1 summarizes the basic methodologies for estimating GHG emissions presented in these protocols. These methodologies coalesce around two different approaches, based on measuring either the input or output of the production process. In general, the output method is less certain, as it involves multiplying production data by emission factors that are likely default values based on purity assumptions. In contrast, the input method is more certain as it generally involves measuring the consumption of each carbonate input and calculating purity fractions. Both the input and output methodologies generally account for the ratio of cullet in the manufacturing process. The IPCC guidelines are discussed more in-depth below.

Many glass manufacturing facilities are required to conduct periodic stack tests of glass melting furnace emissions. Although not specifically required for reporting GHG emissions, the stack tests typically require testing using EPA Method 3 or 3A, which quantifies the CO_2 concentration of the stack gas. These data can be used to estimate the CO_2 emission rates. The frequency for these stack tests depend on state and local requirements; in some cases, the tests are conducted annually; in others, the tests are conducted every 2 to 5 years; and in some cases, periodic stack testing is not required.

Where states require reporting of GHG emissions, the most common method for estimating emissions is based on the IPPC Tier 3 method, assuming the complete volatilization of carbon in the raw materials as CO_2 and a calcination fraction of 1.0.

Table 1. GHG Emissions Estimation Methodologies Reviewed

Reporting Program/Guidance	Methodology
2006 IPCC Guidelines	**For Glass Production**: Three Tiers Tier 1 - based on production-based emission factor for generic glass Tier 2 - based on production-based emission factors for specific types of glass Tier 3 - based on input of carbonate-specific emission factors and actual calcination fraction (% purity), if known; if not know, 100% purity assumed **For Other Process Uses**: Three Tiers Tier 1 - based on total carbonate consumption, assuming 85% limestone, 15% dolomite, 95% purity, and carbonate-specific emission factors Tier 2 - same as Tier 1, but using carbonate-specific consumption data Tier 3 - same as Tier 3 for Glass Production
U.S. Inventory	Nationwide estimates using national production data and IPCC emission factors
Australian National Mandatory Greenhouse Gas Reporting Program	**Default Method** Based on IPCC emission factors carbonate-specific emission factors, but assuming default purity levels of 90% for limestone and 95% for dolomite **Higher Order Method** Same as IPCC Tier 3 Method for Glass Production, but with 100% purity assumed
European Union Emissions Trading System	**Method A: Carbonate Input** Same as IPCC Tier 3 Method for Glass Production, but with 100% purity assumed **Method B: Converted Alkali Earth/Oxides Quantities** Based on emission factors for converted alkali earth/oxides (CaO, MgO, Na_2O) , assuming 100% purity
DOE Technical Guidelines for the Voluntary Reporting of Greenhouse Gases (1605(b))	Same as IPCC Tier 3 Method for Glass Production
European Bank for Reconstruction and Development	Same as IPCC Tier 3 Method for Glass Production, but with 100% purity assumed

4. Options Considered for Reporting Threshold

4.1 Emissions Thresholds

Thresholds of 1,000, 10,000, 25,000, and 100,000 mt of CO_2 were considered. Requiring all facilities to report (no threshold) was also considered. A capacity-based threshold was not considered.

A summary of the emissions and facilities covered per option is presented in **Error! Reference source not found.** An analysis of capacity-based thresholds needs to be provided. Emission estimates were provided by EPA (2006).

The glass manufacturing industry is relatively heterogeneous in terms of the types of facilities. There are some relatively large, emissions intensive facilities, but small artisan shops are common as well. Even at a 1,000 mt threshold, only 58 percent of facilities would be required to report.

4.2 Capacity Thresholds

As noted above, a capacity-based threshold was not considered.

4.3 No Emissions Threshold

The no emissions threshold includes all glass manufacturing facilities included in this Technical Support Document regardless of their emissions or capacity.

Table 3 summarizes emissions and number of facilities covered if there were no emissions threshold.

Table 2. Threshold Analysis for Glass Manufacturing

Source Category	Threshold Level (mt)	Process Emissions (mt CO2e/yr)	Combustion CO2 Eq. Emissions (mt /yr)	Total National Emissions (mt CO2e)	Number of Entities	Emissions Covered		Entities Covered	
						mt CO_2e/yr	Percent	Number	Percent
Glass Manufacturing	100,000	1,649,508	2,775,761	4,425,269	374	207,535	4.7%	1	0.3%
Glass Manufacturing	25,000	1,649,508	2,775,761	4,425,269	374	2,243,583	50.7%	55	14.7%
Glass Manufacturing	10,000	1,649,508	2,775,761	4,425,269	374	4,012,319	90.7%	158	42.2%
Glass Manufacturing	1,000	1,649,508	2,775,761	4,425,269	374	4,336,892	98.0%	217	58.0%

Table 3. No Threshold Analysis for Glass Manufacturing

Source Category	Threshold Level (mt)	Process Emissions (mt CO2e/yr)	Combustion CO2 Eq. Emissions (mt/yr)	Total National Emissions (mt CO2e)	Number of Entities	Emissions Covered		Entities Covered	
						mt CO_2e/yr	Percent	Number	Percent
Glass Manufacturing	None	1,649,508	2,775,761	4,425,269	374	4,425,269	100%	374	100%

5. Options for Monitoring Methods

Three separate monitoring methods were considered for this technical support document: default emission factor approach (Option 1), a carbonate-based input method (Option 2), and direct measurement (Option 3). All of these options would require annual reporting.

When required to report GHG emissions, glass manufacturing facilities generally use a carbonate-based input approach, as described below for Option 2. Many facilities also are required to conduct periodic stack tests. Although the intent of these tests is not to quantify GHG emissions, the data can be used to estimate annual emissions of CO_2. However, this approach is not currently used or required for annual reporting.

5.1 Option 1: Default Emission Factor Method

The default emission factor methods are based upon the IPCC Tier 1 and Tier 2 methodologies (IPCC 2006). The Tier 2 method is an output-based approach. The Tier 2 equation is as follows:

$$E_{CO2} = \sum_{i=1}^{n} M_i \bullet EF_i \bullet (1 - CR_i)$$

Where:

E_{CO2}	=	Process emissions of CO_2 (mt).
n	=	Number of glass types produced.
M_i	=	Mass of glass type i produced (mt).
EF_i	=	Emission factor for glass type i (mt CO_2 / mt glass).
CR_i	=	Cullet ratio for glass type i (unitless dimension).

The IPCC Guidelines provides the emission factors to be used in the above equation for flat glass, container glass, fiberglass, and several types of specialty glasses.

The Tier 1 method uses a default emission factor based on the total amount of glass rather than each glass type. The equation is similar to the Tier 2 equation shown below.

5.2 Option 2: Carbonate Input Method

The approach used in Option 2 combines the direct measurement of inputs with the emissions calculations based on stoichiometric ratios. This approach is based upon the IPCC Tier 3 method, which is an input-based approach. This approach requires facilities to determine their calcination fractions (or assume a value of 1.0) and determine the weight fraction of their carbonate inputs, and then apply this information to their carbonation consumption. In other words:

$$E_{CO2} = \sum_{i=1}^{n} MF_i \bullet M_i \bullet EF_i \bullet F_i$$

Where:

E_{CO2} = Process mass emissions of CO_2 (mt/yr) from the furnace.

n = Number of carbonate-based raw materials charged to furnace.

MF_i = Mass fraction of carbonate-based mineral ***i*** in carbonate-based raw material ***i*** (dimensionless unit).

M_i = Mass of carbonate-based raw material ***i*** charged to furnace (mt/yr).

EF_i = Emission factor for carbonate-based raw material ***i*** (metric ton CO_2/metric ton carbonate-based raw material).

F_i = Fraction of calcination achieved for carbonate-based raw material ***i***, assumed to be equal to 1.0 (dimensionless unit).

The emission factors used in the above equation are taken from the IPCC Guidelines and are based on the assumption that the carbon in the carbonate materials charged to the furnace form, and are released as, CO_2. These emission factors are presented in Table 4.

Table 4. CO_2 Emission Factors for Carbonates Used in Glass Manufacturing

Mineral Name - Carbonate	CO_2 Emission Factor (tons CO_2/ton carbonate)
Calcite/aragonite - $CaCO_3$	0.440
Dolomite - $CaMg(CO_3)_2$	0.477
Sodium Carbonate/Soda Ash - Na_2CO_3	0.415

Source: IPCC (2006) *2006 IPCC Guidelines for National Greenhouse Gas Inventories*

5.3 Option 3: Direct Measurement

Direct measurement constitutes either measurements of the GHG concentration in the stack gas and the flow rate of the stack gas using a Continuous Emissions Monitoring System (CEMS), or periodic measurement of the GHG concentration in the stack gas and the flow rate of the stack gas using periodic stack testing. However, the stack testing method was not considered for the glass manufacturing industry given the complexity in adjusting for the variability in stationary combustion related CO_2 emissions. Under a CEMS approach, the emissions measurement data would be reported annually and account for both combustion and process related CO_2 emissions as emissions are exhausted through a common stack.

Elements of a CEMS include a platform and sample probe within the stack to withdraw a sample of the stack gas, an analyzer to measure the concentration of the GHG (e.g., CO_2) in the stack gas, and a flow meter within the stack to measure the flow rate of the stack gas. The emissions are calculated from the concentration of GHGs in the stack gas and the flow rate of the stack gas. The CEMS continuously withdraws and analyzes a sample of the stack gas and continuously measures the GHG concentration and flow rate of the stack gas.

6. Procedures for Estimating Missing Data

Options and considerations for missing data would vary depending on the monitoring method. Each option would require a complete record of all measured parameters as well as parameters determined from company records that are used in the GHG emissions calculations (e.g., carbon contents, monthly fuel consumption, etc.). Therefore, whenever a quality-assured value of a required parameter is unavailable (e.g., if a monitor or CEMS malfunctions during unit operation or if a required fuel input parameter is not obtained), a substitute data value for the missing parameter must be used in the calculations.

6.1 Procedures for Option 1: Default Emission Factor Method

For process sources in the glass manufacturing category that use Option 3, only glass production data and the process cullet ratio is required. If a monthly measurement of glass production and/or the cullet ratio is not available, the substitute data value would be the arithmetic average of the quality-assured values of that parameter for the months immediately preceding and immediately following the missing data incident. If, for a particular parameter, no quality-assured data are available prior to the missing data incident, the substitute data value would be the first quality-assured value obtained after the missing data period.

6.2 Procedures for Option 2: Carbonate Input Method

For process sources in the glass manufacturing category that use Option 2, the data requirements include the mass, carbonate content, and fraction of calcination achieved for each carbonate process input on a monthly basis. If a monthly measurement of the carbonate content is not obtained or data from continuous measurements of the mass rate of process inputs and process outputs is not available, the substitute data value would be the arithmetic average of the quality-assured values of that parameter from the previous month and the month immediately following the missing data incident. For data on the mass fractions of carbonate-based minerals in the carbonate-based raw materials, missing data would be replaced using the assumption that the mass fraction of each material is 1.0.

6.3 Procedures for Option 3: Direct Measurement Using CEMS

For options involving direct measurement of CO_2 emissions using CEMS, Part 75 establishes procedures for the management of missing data. Specifically, the procedures for managing missing CO_2 concentration data are specified in §75.35. In general, missing data from the operation of the CEMS may be replaced with substitute data to determine the CO_2 emissions during the period for which CEMS data are missing. Section 75.35(a) requires the owner or operator of a unit with a CO_2 CEMS to substitute for missing CO_2 pollutant concentration data using the procedures specified in paragraphs (b) and (d) of §75.35; paragraph (b) covers operation of the system during the first 720 quality-assured operation hours for the CEMS, and paragraph (d) covers operation of the system after the first 720 quality-assured operating hours are completed.

During the first 720 quality-assured monitor operating hours following initial certification at a particular unit or stack location, the owner or operator would be required to substitute CO_2 pollutant concentration data according to the procedures in §75.31(b). That is, if prior quality-assured data exist, the owner or operator would be required to substitute for each hour of missing data, the average of the data recorded by a certified monitor for the operating hour immediately preceding and immediately following the hour for which data are missing. If there are no prior quality-assured data, the owner or operator would have to substitute the maximum potential CO_2 concentration for the missing data.

Following the first 720 quality-assured monitor operating hours, the owner or operator would have to follow the same missing data procedures for SO_2 specified in §75.33(b). The specific methods used to estimate missing data would depend on the monitor data availability and the duration of the missing data period.

7. QA/QC Requirements

Facilities should conduct quality assurance and quality control of the production and consumption data, supplier information (e.g., carbonate contents), and emission estimates reported. Facilities are encouraged to prepare an in-depth quality assurance and quality control plan which would include checks on production data, the carbon content information received from the supplier and from the lab analysis, and calculations performed to estimate GHG emissions. Several examples of QA/QC procedures are listed below.

7.1 Stationary Source Combustion Emissions

Facilities should follow the guidelines given by the Stationary Combustion Source TSD (Docket No. EPA-HQ-OAR-2008-0508-004).

7.2 Process Emissions

Options and considerations for QA/QC will vary depending on the proposed monitoring method. Each option would require unique QA/QC measures appropriate to the particular methodology employed to ensure proper emission monitoring and reporting.

For units using CEMS to measure CO_2 emissions, the equipment should be tested for accuracy and calibrated as necessary by a certified third party vendor. These procedures should be consistent in stringency and data reporting and documentation adequacy with the QA/QC procedures for CEMS described in Part 75 of the Acid Rain Program.

For units using CEMS to measure CO_2 emissions, the equipment should be tested for accuracy and calibrated as necessary by a certified third party vendor. These procedures should be consistent in stringency and data reporting and documentation adequacy with the QA/QC procedures for CEMS described in Part 75 of the Acid Rain Program (EPA 2008a).

7.3 Data Management

Data management procedures should be included in the QA/QC Plan. Elements of the data management procedures plan are as follows:

- For measurements of carbonate content, assess representativeness of the carbonate content measurement by comparing values received from supplier and/or laboratory analysis with IPCC default values.

- Check for temporal consistency in production data, carbonate content data, and emission estimate. If outliers exist, they should be explained by changes in the facility's operations or other factors. A monitoring error is probable if differences between annual data cannot be explained by:
  - Changes in activity levels,
  - Changes concerning fuels or input material,
  - Changes concerning the emitting process (e.g. energy efficiency improvements) (European Commission 2007).

- Determine the "reasonableness" of the emission estimate by comparing it to previous year's estimates and relative to national emission estimate for the industry:
  - Comparison of data on fuel or input material consumed by specific sources with fuel or input material purchasing data and data on stock changes,
  - Comparison of fuel or input material consumption data with fuel or input material purchasing data and data on stock changes,
  - Comparison of emission factors that have been calculated or obtained from the fuel or input material supplier, to national or international reference emission factors of comparable fuels or input materials
  - Comparison of emission factors based on fuel analyses to national or international reference emission factors of comparable fuels, or input materials,
  - Comparison of measured and calculated emissions (European Commission 2007).

- Maintain data documentation, including comprehensive documentation of data received through personal communication:
  - Check that changes in data or methodology are documented

8. Types of Emission Information to be Reported

8.1 Types of Emissions to be Reported

Glass facilities should report both process (CO_2) and combustion related (CO_2, CH_4, and N_2O) greenhouse gas emissions. The data to be reported may vary depending on monitoring options selected. However, all glass facilities should report the total annual emissions from each continuous glass melting furnace, number of continuous glass melting furnaces, quantity of each carbonate-based raw material charged to each continuous glass melting furnace, quantity of glass produced by each continuous glass melting furnace, and the carbonate-based mineral mass fraction for each carbonate-based raw material charged to a continuous glass melting furnace (if applicable). For reporting options for stationary combustion refer to EPA-HQ-OAR-2008-0508-004.

8.2 Other Information to be Reported

8.2.1 Option 1: Default Emission Factor Method

For the default emission factor method, the facility should report its glass production and process cullet ratio in addition to GHG emissions.

8.2.2 Option 2: Carbonate Input Approach

For the carbonate input method, in addition to GHG emissions, the facility should report its carbonate consumption and the fraction of calcination achieved (or assumed) for each carbonate input.

8.2.3 Option 3: Direct Measurement

For options based on direct measurement using a CEMS, the GHG emissions are directly measured at the point of emission. The facility should report the GHG emissions measured by the CEMS for each monitored emission point and should also report the monitored GHG concentrations in the stack gas and the monitored stack gas flow rate for each monitored emission point. These data would illustrate how the monitoring data were used to estimate the GHG emissions.

The facility should report the following data for direct measurement of emissions using CEMS:

- The unit ID number (if applicable);
- A code representing the type of unit;
- Maximum product production rate and maximum raw material input rate (in units of metric tons per hour);
- Each type of raw material used and each type of product produced in the unit during the report year;
- The calculated CO_2, CH_4, and N_2O emissions for each type of raw material used and product produced, expressed in metric tons of each gas and in metric tons of CO_2e;
- A code representing the method used to calculate the CO_2 emissions for each type of raw material used (e.g., part 75, Tier 1, Tier 2, etc.);

- If applicable, a code indicating which one of the monitoring and reporting methodologies in part 75 of this chapter was used to quantify the CO_2 emissions;
- The calculated CO_2 emissions from sorbent (if any), expressed in metric tons; and
- The total GHG emissions from the unit for the reporting year, i.e., the sum of the CO_2, CH_4, and N_2O emissions across all raw material and product types, expressed in metric tons of CO_2e.

8.3 Additional Data to be Retained Onsite

Facilities should be required to retain data concerning monitoring of GHG emissions onsite for a period of at least five years from the reporting year. For CEMS, these data would include CEMS monitoring system data including continuous-monitored GHG concentrations and stack gas flow rates, calibration, and quality assurance records. Process data including process raw material and product feed rates and carbonate contents should also be retained on site for a period of at least five years from the reporting year. EPA could use such data to conduct trend analyses and potentially to develop process or activity-specific emission factors for the process.

9. References

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